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A GEOLOGIST VIEWS THE ENVIRONMENT

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A GEOLOGIST VIEWS THE ENVIRONMENT*

John C. Frye

When the geologist considers the environment, and particularly when he is concerned with the diversified relations of man to his total physical environment, he takes an exceptionally broad and long-term view. It is broad because all of the physical features of the earth are the subject matter of the geologist. It is long term because the geologist views the environment of the moment as a mere point on a very long time-continuum that has witnessed a succession of physical and biological changes—and that at present is dynamically undergoing natural change.

Let us first consider the time perspective of the geologist, then consider the many physical factors that are important to man's activity on the face of the earth, and, third, turn our attention to specific uses of geologic data for the maintenance or development of an environment that is compatible with human needs.

THE LONG VIEW

The earth is known to be several billion years old, and the geologic record of physical events and life-forms on the earth is reasonably good for more than the most recent 500 million years. Throughout this span of known time the environment has been constantly changing—sometimes very slowly, but at other times quite rapidly. Perhaps a few dramatic examples will serve as illustrations. Less than 20,000 years ago the area occupied by such North American cities as Chicago, Cleveland, Detroit, and Toronto were deeply buried

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* Prepared for "Voice of America," Earth Science Series, Dr. Charles F. Park, Jr., Coordinator.

under glacial ice. The land on which New York City is now built was many miles inland from the seashore. And part of the area now occupied by Salt Lake City lay beneath a fresh-water lake. Twelve thousand years ago glacial ice covered the northern shores and formed the northern wall of what was then the Great Lakes, and much of the outflow from those lakes was to the Gulf of Mexico rather than to the Atlantic Ocean through the St. Lawrence River, as it is now. Although firm scientific information is not available to permit equally positive statements about atmospheric changes during the past few tens of thousands of years, deductions from the known positions of glaciers and from the fossil record make it clear that the atmospheric circulation patterns were quite different from those of the present, and studies of radiocarbon show that the isotopic content of the atmosphere changed measurably through time.

The purpose of listing these examples is to emphasize that the environment is a dynamic system that must be understood and accommodated by man's activities, rather than a static, unchanging system that can be "preserved." The living, or biological systems of the earth are generally understood to be progressively changing, but much less well understood by the public is that the nonliving, physical aspects of the earth also undergo change at an equal or greater rate.

Clearly, a dynamic system is more difficult to understand fully, and it is more difficult to adapt man's activities to a constantly changing situation than to an unchanging or static system. On the other hand, the very fact of constant change opens many avenues of modification and accommodation that would not be available in a forever constant and unchanging system.

THE PROBLEM

Although it is important that we have in mind the long-term facts concerning earth history, modern man has become such an effective agent of physical and chemical change that he has been able to produce major modifications, some of which run counter to the normal evolution of our earthly environment, and to compress millennia of normal evolutionary changes into days. These rapid modifications are, almost without exception, made by man with the intention of producing improvements and advantages for people. Problems result from the fact that by-products and side effects do occur that are neither desirable nor pleasing, and at some times and places may be hazardous or even calamitous. In some cases the undesirable side effects are unknown or are unpredictable; in other cases they are tolerated as a supposed "necessary price" to pay for the desirable end result. It is our intent to examine the role of the earth scientist in defining some of these problems and in devising ways of minimizing or eliminating them.

The ways in which man treats his physical surroundings, produces and uses the available nonliving resources, and plans for his future needs are, of course, social determinations. However, in order that social decisions can be made in such a way that we, and our children, will not find reason to regret them, they should be made in the light of all the factual information that it

is possible to obtain. If we, collectively, decide to use the available supply of a nonrenewable resource—for example, petroleum—at a particular rate, we should know how long it will last and what substitute materials are available to replace it when the supply is exhausted; if we decide to dam a river, we should know what the side effects will be in all directions, how long the facility will last, and what the replacement facility might be; if we develop huge piles of discarded trash, we should know whether or not they will cause pollution of water supplies or the atmosphere, and whether or not the terrane is sufficiently stable to retain them; if we substitute one fuel for another with the desire to abate air pollution, we should know if it will make a net over-all improvement in the pollution problem, and if it will be available in the quantity required so that man's needs can be met; and if we plan expanding metropolitan areas we should have full information on the terrane conditions at depth and on the raw material resources that will be rendered unusable by urbanization.

ROLE OF EARTH SCIENCE IN SOLVING PROBLEMS

When we consider the role of earth science in solving problems, we see that the earth sciences can and should develop answers to all of the questions we have asked. Many of the problem areas overlap one another, but it will be easier to discuss them if we class the contributions of the earth scientist to environmental problem solving in five general categories. The first of these is collecting data for planning the proper use of the terrane, or perhaps we should say the most efficient adjustment of man's use of the earth's surface to all of the physical features and characteristics at and below the surface—particularly in expanding urban areas. Second is determination of the factors that influence the safety and permanence of disposal of waste materials and trash of all kinds—both in the rocks near the surface and at great depth in mines and wells. Third is providing information for the planning and development of safe, adequate, and continuing water supplies in locations that will serve populated areas. Fourth is the identification of rock and mineral resources to provide for future availability of needed raw materials, or of appropriate substitute materials. And, fifth is the recognition of man as a major geologic agent by monitoring the changes he has caused in his environment and by providing remedies where these changes are, or may become, harmful.

Proper Use of Land

The first of these general categories—procuring data for physical planning of the proper use of the land surface and of the rocks below the surface—covers data provided by topographic and geologic maps, by engineering geology and soil mechanics investigations, by predictions of potential landslides and other geologic hazards, and by a complete inventory of available mineral resources and future potential water supplies. Much of the geologic data needed in this category can be produced by conventional methods of research, but, to be effective, the research program must be oriented toward

environmental applications. Furthermore, the results must be presented in a form that is readily understandable to, and usable by, planners and administrators who often are unfamiliar with science and, particularly, do not have a working knowledge of the geological sciences. Perhaps the best way to explain what I mean by environmental orientation is to cite a few examples.

The first example of the use of geologic research oriented for planning is a laboratory study involving clay mineralogy, petrography, and chemistry. It was prompted by numerous incidences of structural failure of earth materials. In rapidly expanding suburban residential areas there has been a great increase in the use of septic tanks and, simultaneously, a rapid increase in the household use of detergents and water softeners. A laboratory research program was initiated to study the changes induced in the clay minerals by these chemical substances when they were introduced into the near-surface deposits by discharge from septic tanks. Preliminary results showed that the materials in septic tank effluent did, indeed, produce significant and undesirable changes in the properties of some earth materials. The data made it possible to predict changes that could occur in the structural characteristics of common surficial deposits and, thus, to prevent structural failure. Therefore, the conclusions were presented to planners, health officials, architects, and other groups that might have need of the information.

In strong contrast to such a sharply focused and specific research project is a second example provided by a study of a county at the northwest fringe of the Chicago metropolitan area, into which urbanization is spreading from that metropolis. Because of impending problems, the county government organized a regional planning commission, which called upon the State Geological Survey and other agencies to collect data on the physical environment that were essential to wise, long-range planning. Where some of the fields of activity of the agencies overlapped, they cooperated informally so that they could most effectively work with the planning commission. Essential to the project were modern topographic maps of the county, and, even though much of the county had been geologically mapped previously, several man-years of geologist time were devoted to the project.

This project to characterize the physical environment involved many types of geological study. These included (1) analysis of the physical character of the major land forms within the county; (2) interpretation of the relation between geologic units near the surface and the agricultural soil units; (3) establishment of the character of the many layers of rocks and glacial deposits penetrated at depth by drilling below the surface; (4) definition of the occurrence and character of water-bearing strata in the near-surface glacial deposits and the deeper bedrock layers; (5) determination of the geologic feasibility of water-resource management programs; (6) determination of the geologic feasibility of waste management programs; (7) delineation of the geographic occurrence and description of the characteristics of construction material resources; (8) location of commercial mineral resources and assessment of their economic value; (9) determination of the engineering characteristics of the geologic units near the surface; and (10) geologic evaluation of surface reservoir conditions and proposed reservoir sites.

The approach to such development of data includes field work by surficial geologists, engineering geologists, ground-water geologists, stratigraphers, and economic geologists. In the laboratory, chemists, mineralogists, and stratigraphers conduct studies of the subsurface by use of cores and cuttings of the deposits at all depths; make chemical, mineralogical, and textural analyses of all deposits and rocks; determine physical properties; compile statistics; and make economic analyses of the many mineral resource situations. The results of these studies are compiled on interpretative maps, which the planning commission combines with the results of studies by specialists of other agencies and by the commission itself for preparation of maps that show the recommendations for land use. These maps, together with explanatory, nontechnical text, serve as a basis for county zoning and long-range development planning.

Development of Waste Disposal Facilities

Our second category of environmental geologic information includes those geologic data needed for proper and safe development of waste disposal facilities. Man has the propensity to produce toxic and noxious waste materials in progressively increasing quantity and in an ever-increasing variety and degree. Waste products result from manufacturing, processing, and mining—but of even greater concern is the concentrated production of waste by the inhabitants of our large cities. Traditionally, man has used fresh water to dilute liquid waste and the atmosphere to dilute the gaseous waste products of combustion. He has often indiscriminately used the land or large bodies of water for disposal of solid waste. However, even the general public is now aware of the fact that we are exhausting the capacity of fresh waters and the atmosphere to absorb our waste products. Along the sea coasts there is still the ocean—although even the ocean is being restricted as a waste disposal medium—but in the vast region of the continental interior we have no ocean in which to dump our wastes. Instead, our choices are limited to (1) selective recycling, accompanied by essentially complete purification of the residue of waste materials; (2) selective recycling accompanied by land disposal of nonrecyclable residues; or (3) the use of the rocks of the earth's crust for the total future expansion of waste disposal capacity. Geologists, who traditionally have been concerned with the discovery of valuable deposits of minerals and their extraction from the crust, now also must concern themselves with the study of the rocks of the earth's crust as a possibly safe place for the disposal and containment of potentially harmful waste products.

Petroleum geologists were introduced to one aspect of the problem of large quantity underground disposal of waste material more than a quarter century ago when it became necessary to find methods for injecting into deep wells the increasing quantities of brines produced with petroleum in oil fields. However, it was not until population densities approached their present levels that we became genuinely concerned with the most critical problems of the future—that is, the safe disposal of industrial and human waste materials in large quantity, other than by dilution. As some of these undesirable materials are destined to increase at an exponential rate in the future, it is obvious that we must devote our best geologic effort to solution

of the problems of disposal. The problem of disposal of high-level and intermediate-level radioactive wastes has already attracted a major research effort, probably because these radioactive materials are obviously so highly dangerous for such a long period of time, and a body of scientific data now exists concerning their safe management.

In my own state of Illinois, solid waste disposal is generally accomplished by sanitary landfill, and frequently the State Geological Survey is asked by state and local departments of health to make geologic evaluations of proposed sites. However, precise and universally accepted criteria for this type of evaluation are only now being developed. Several disposal sites of differing geologic character are being intensively studied by coring and instrumentation of test holes, and analyses are being made of the liquids leached from the wastes and the containing deposits. In addition to laboratory study of the obvious characteristics of the containing deposits—such as texture, permeability, strength, clay mineralogy, and thickness of the units that do not transmit water (and thus protect the aquifers)—studies must be made of the less obvious effects of the seepage of liquids on the structural character of the deposit, the removal of objectionable chemicals from water solutions by the clay minerals of the containing deposits, and the microflow patterns of water in earth materials surrounding the wastes. For some of these determinations it is necessary to know the chemical composition of the liquids that pass through the wastes, as well as the chemistry and mineralogy of the deposits that contain them.

Disposal near the surface by landfill or lagooning methods requires detailed studies of the earth deposits at and immediately below the surface, with only minor data required on the deeper bedrock. On the other hand, disposal of industrial wastes in deep wells requires studies of the character and continuity of all rock layers down to the crystalline basement. Geologic data needed for deep disposal involve a combination of the types of information needed for the exploration for both oil and water, plus a knowledge of the confining beds of shale or clay. It should also enable us to predict possible changes that might be produced by the injected wastes.

A different type of pollution problem is represented by sulfur compounds and other undesirable materials released by the burning of coal, oil, and gas and discharged into the atmosphere. The earth scientist contributes to the solution of this problem by studies of the mineral matter in the coal, studies of methods of processing the coal before it is burned, studies of means of removing the harmful materials from the effluent gases produced by combustion, and research on the conversion of coal into gaseous or liquid fuels from which much of the objectionable material can be extracted.

Planning Water Supplies

The third category of concern for the earth scientist is water, its occurrence, quality, continuing availability, and pollution; its use as a resource, as a diluent for waste materials, as a facility for recreation, and as an aesthetic attribute. Many of the problems and areas of data collection for

water resources fall mainly in the province of the engineer, the chemist, the biologist, or the geographer. But, it would be unrealistic to exclude water from the subjects requiring significant and major data input by the geologist, because to a greater or lesser degree geologic data is needed for the proper development and management of each of the above aspects. The occurrence, quality, availability, development, and replenishment of ground water require major attention by the geological scientist because all of these aspects are directly controlled by the character of the rocks at and to considerable distances below the surface.

Of the categories of environmental data we are discussing, water resources and water pollution are the most widely discussed in the news media and most generally recognized by the public and by municipal planners and administrators. Furthermore, an extensive cadre of earth scientists specializing in water-related problems has developed within governmental agencies and industry. There are many examples of the application of geologic data to management of water resources, ranging from dam site evaluations to the mapping of aquifers and determination of areas suitable for artificial recharge. Before we leave this category, however, I should point out that, in contrast to the rock and mineral resources of the earth's crust, water is a dynamic and renewable resource and, therefore, is subject to management. Even the long-range correction of the effects of unwise practices in the past may be possible in some cases.

Future Availability of Rock and Mineral Materials

Our fourth category is, perhaps, the most complicated aspect of environmental geology. It is the problem of assuring adequate supplies of mineral and rock raw materials for the future, and especially of assuring their availability near densely populated areas where they are most needed. We have an increasing shortage of raw material resources to meet the needs of the increasing world population, and also a mounting conflict of interest for land use in and adjacent to our urbanizing regions. Conflict exists in populated regions because buildings and pavements commonly remove the possibility of extracting the rock or mineral raw materials underneath them. While the producer of rock or mineral products is exploring for the best deposit available from both a physical and economic standpoint, the urban developer may be planning surface installations without regard for the presence or absence of rock and mineral deposits, which he may be rendering unavailable. These unavailable resources may be urgently needed for community developments in the future, and it is important that the attitudes of the planner and mineral producer be brought into harmony, and that compatible working relations be evolved so that mineral resource development can move forward as an integral part of the urban plan. The geological sciences can supply an accurate and detailed description and maps of all of the rock and mineral resources, not only in but also surrounding urbanizing areas for a distance reasonable for transporting bulk commodities to the metropolitan centers. Grades of deposits that might have utility in the coming 25 to 50 years as well as grades currently being developed should be included in the study.

An equally important role of the earth scientists now, and more particularly in the future, lies in regions remote from the cities where exploration

is needed for the raw materials and fuels required by modern society. Although this topic has been discussed in detail in other talks in this series, it is mentioned here because it is a vital element of environmental application. Furthermore, research by the earth scientist, directed toward the identification of substitute materials and toward meeting more exacting and different specifications for future needs, is called for if we are to keep pace with expanding human needs. Information about natural resources is just as essential a part of needed environmental data as are flood hazard maps, physical data maps for engineering projects, and aquifer maps indicating the occurrence of ground-water supplies.

Man as a Geologic Agent

Our fifth area is the recognition of man as a geologic agent, and here we have the culmination of the problems of Environmental Geology. Man's changes in his physical surroundings are made in order to obtain some real or imagined advantage for people. Some of these changes are designed to prevent natural events from happening and include levees and detention reservoirs to prevent flooding of land, revetments and terracing to prevent erosion, and irrigation to prevent the effects of droughts. But many other changes are intended to produce effects that are not in the natural sequence of things. In both cases, nature is liable to provide unplanned and undesirable side effects. It is the role of the earth scientist to determine the effects of man-made physical changes on all aspects of the physical environment before structural changes are made so that provision can be made to negate undesirable by-product effects—or, if the side effects are too severe, so that a decision against the environmental changes can be made.

A special facet of man-made changes is in the area of mineral and fuel resources. The public need and demand for energy, and for products based on mineral raw materials, is constantly increasing at the same time that increasing populations require that land resources be maintained at maximum utility. Here again, the earth scientist must add to his traditional role of finding and developing sources of energy and mineral resources the equal or more difficult role of devising methods of producing these resources in such a way that land resources have a maximum potential for other human uses. This has led to the concept of planning for multiple sequential use—that is, designing a mineral extraction operation in advance so that the land area will first have a beneficial use before the minerals need to be extracted, then be turned over to mineral extraction, and, finally, be returned to a beneficial use, perhaps quite different from the original use.

CONCLUSIONS

The earth scientist is concerned with the physical framework of the environment wherever it may be, with the supply of raw materials essential to modern civilization, and with the management of the earth's surface so that it will all have maximum utility for its living inhabitants. It is this last item that is a relatively new role for the earth scientist, and one in which he must

work cooperatively with the engineer, the biologist, and the social scientist. The earth scientist must become the interpreter of the physical environment, and he must do it in the long-term context of a dynamically changing earth so that "architectural" designs will be in harmony with natural forces 50, 100, or 500 years from now, as well as with the conditions of the moment.

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